Drag Reduction Program

Dr. Penrose (Parney) C. Albright

palbright@darpa.mil

What are we trying to accomplish?

Develop friction-drag-reduction technology …

- **With *demonstrable operational* value to the future naval and/or sealift fleets**
- **Using extensive computational modeling and experiments**

We will exploit *new approaches to multi-scale modeling…*

- **Developed within the materials science community**
- **Enabled by massively parallel computer architectures**

To develop a *multi-scale modeling capability* for **turbulent flow**

We will leverage the simulation results to guide *focused* near-full-scale (Re~10^8) experiments

Drag reduction implications

Speed at constant power is a <u>weak</u> function of drag

- **At least ~50% reduction in friction drag is required to meaningfully *increase speed***
  - **Promising only when residual drag is <u>insignificant</u>**

<u>Proportional</u> reduction in fuel consumed at constant speed

- **Potential increase in payload**
  - **Long-range (long-endurance) ships have large fuel fractions ~0.2-0.5**
  - **Military ships typically have small payload fractions — 0.1 or less**
  - **E.g., 20% friction drag reduction ~50% increase in payload**

<u>Proportional</u> increase in range and endurance at constant speed

- **Reductions in friction drag of <~20% probably uninteresting**

Where we are today

Friction drag constitutes…

- **Roughly 50% of the drag on surface ships**
- **Roughly 65% of the drag on submarines**

Decades of research have identified two very promising techniques for reducing friction drag: polymers and microbubbles

- **70-80% reduction in skin-friction drag coefficient *in the laboratory***
- **But, success in the *practical* implementation of these techniques has eluded us for more than 25 years**
  - **Too much polymer has to be carried, and the polymer degrades at high speeds**
  - **Power requirements for injecting microbubbles are below the break-even point**

Where we are today: Polymers

Key Results

~80% reduction in drag in small-scale lab experiments

- ~50% reduction for short periods in full-scale experiments

Significant recent advances in first-principles modeling

- Direct Numerical Simulation (DNS) with a constitutive relation for the polymer stress tensor
- Excellent qualitative agreement with experimental observations associated with drag reduction
- Indicated potential for optimization
  - E.g., equivalent drag reduction at 1/10 the needed concentration with 3× polymer chain extensibility

Limitations

Number of grid points needed for a DNS simulation of *ship* flow prohibitive

Computational state-of-the-art for polymer modeling $Re_d \sim 5 \times 10^3$

$\sim 10^6$ grid points

Ship $Re_d \sim 10^6$

Number of grid points needed $\sim (Re)^{9/4}$

Where we are today: Microbubbles

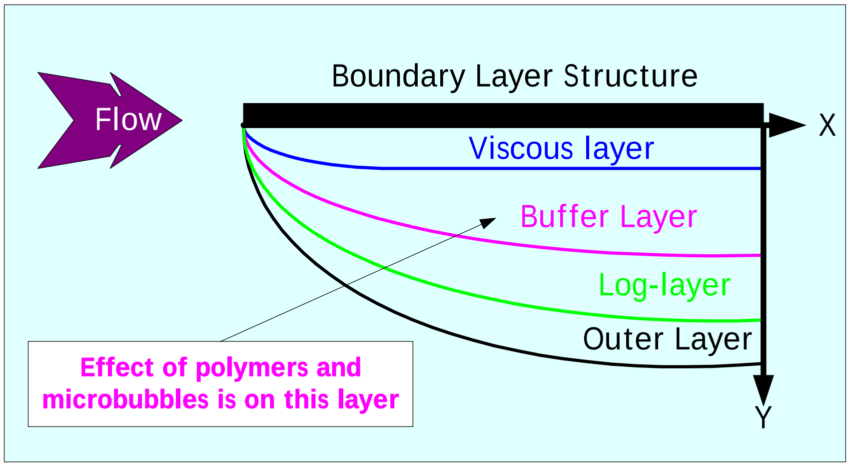
Key Results

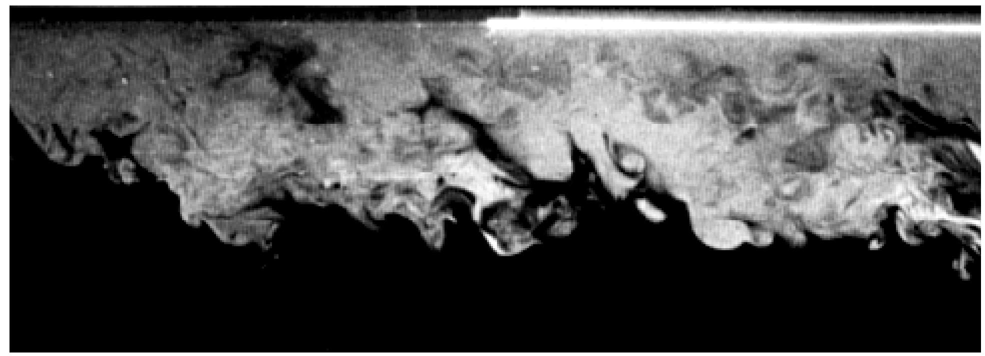
- ~80% reduction in drag demonstrated in small-scale experiments
- No full-scale data (Japanese planning an experiment)

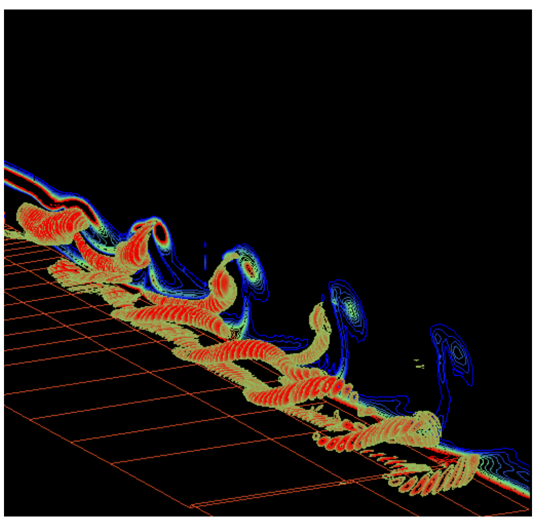
Limitations

- Experimental results at low Re ($\sim 10^6$)
- No validated or accepted theory
- Rudimentary modeling; No DNS-level computations attempted

Impact of Polymers and Microbubbles







Polymers and microbubbles inhibit hairpin vortex formation—the source instability for boundary layer turbulence

Approach (1 of 2)

Develop a *multi-scale* modeling capability

RANS modeling regime
$Re_x \sim 10^8$

LES modeling regime
$Re_x \sim 10^7$

- **Models for KE; τ; ε; Π**
- **Boundary conditions**

DNS modeling regime
$Re_x \sim 10^5$

- Exact behavior at all scales
- Detailed modeling of different drag-reduction mechanisms
- Parametric studies

- **Subgrid models**
- **Boundary conditions**

Approach (2 of 2)

Perform *focused* experiments

Subscale (e.g., flat plate) experiments to test computational insights

Near-full-scale tests (Re~10^{8+}) with *test-bed models* that address candidate high-payoff friction drag reduction concepts

- With DNS, determine best drag reduction candidates
- With engineering models, determine best implementation candidates

Fully exploiting simulation results at both *small* and *large* scales allows intelligent experimentation that is affordable and effective

Mid-term and Final Exams

Mid-term exam (~2.5 years)

Have we demonstrated a capability to predict the best techniques for drag reduction and their implementation?

- **If yes, then do we believe we can achieve a 30–50% reduction in skin-friction drag *that can be practically implemented*?**
- **If no, then do we have high confidence that a continuation of the computational effort for 2 more years will be successful?**

Final exam (4.5 years)

Have we demonstrated and experimentally validated a predictive modeling capability for skin friction drag reduction?

Have we demonstrated a 30–50% reduction in skin-friction drag *that can be practically implemented*?

Are these results validated in near-full-scale experiments?

Summary

- Revolutionary friction-drag reduction (~50%) should be established as program goal
- Decades of research can be leveraged to move toward militarily important technology
  - Considerable work done from molecular-scale theoretical through full-scale experimental regimes
  - Not reduced to practice after more than 25 years
- Massively-parallel super computers, computational techniques, and existing experimental facilities could enable a breakthrough
  - Multi-scale modeling of turbulent drag reduction
  - Near-full-scale experiments closely coupled with models